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Subjective time estimation by humans is increased by counterclockwise but not clockwise circumcerebral rotations of phase-shifting magnetic pulses in the horizontal plane

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Abstract

Volunteers were required to estimate 10-s intervals after 2.5 min exposures to each of six different patterns of complex magnetic fields. The approximately 10 μT fields were applied sequentially through eight solenoids that were arranged circumcerebrally (every 45 deg) at the level of the temporoorbital plane. There were three rates of change for the circumcerebral rotations whose durations ranged between about 200 and 2000 ms. Successive additions of 20 ms of the complex fields during the counterclockwise circumcerebral rotation at each solenoid distended subjective time most effectively. Subjective time of the group who received these counterclockwise rotations was about 3 s longer than the group who received the clockwise rotations (explaining approximately 50% of the variance). The results are consistent with the model that the temporal binding for experience, most likely a feature of the rostrocaudal waves recreated every approximately 20 ms over the cerebral cortices, can be modified by weak magnetic fields whose spatial direction and temporal complexity are designed to interact with this process. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

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As predicted in 1933 by E.G. Boring in 'The Physical Dimensions of Consciousness' [1] the understanding and the control of conscious perception would require the technology to isolate and to interact with the neurophysical correlates of cognition. The theoretical concepts of Edelman [2] and the empirical observations of Llinas and Ribary [3] have strongly indicated that the temporal substrate to conscious awareness may be re-created every approximately 20–25 ms (the '40 Hz' electroencephalographic band) through re-entrant processes that involve the entire cerebral cortical manifold. The electromagnetic fields generated by these re-entrant processes, transcerebrally, result in a 'binding factor' that allows intracortical fields to interact.

Some of the emergent properties from the interactions generated by the temporal binding [8] may be awareness of the collections of sensations and thoughts that we call 'the present moment' [14]. Comparisons of objective (clock) times with their subjective estimations have been employed as one inference to discern changes in the duration of the temporal binding that subserves cognition. Although motor and sensory temporal performances requiring durations less than 1 s emphasize the lateral cerebellum [9], estimations of longer temporal increments may involve primarily the right frontal and the right parietal cortices [7,11].

Our goal has been to directly interact with and to control the electromagnetic correlates of consciousness generated by the brain through applied, complex magnetic fields whose characteristics simulate natural, transcerebral electromagnetic fields. We have assumed that the continuously reconstructed neuroprocesses associated with the conscious experience of time (duration) is analogous to a second derivative superimposed upon the first derivative ('re-entrant process') generating consciousness. This concept would be compatible with Friston's [5] idea that the functional integration of cerebral activity is due to ongoing and continuous transients as non-linear systems attenuate towards attractors that themselves change (due to modulatory interactions among different populations of neurons) from moment to moment.

To test this hypothesis we employed a prospective method of time estimation as defined by Zakay et al. [18],

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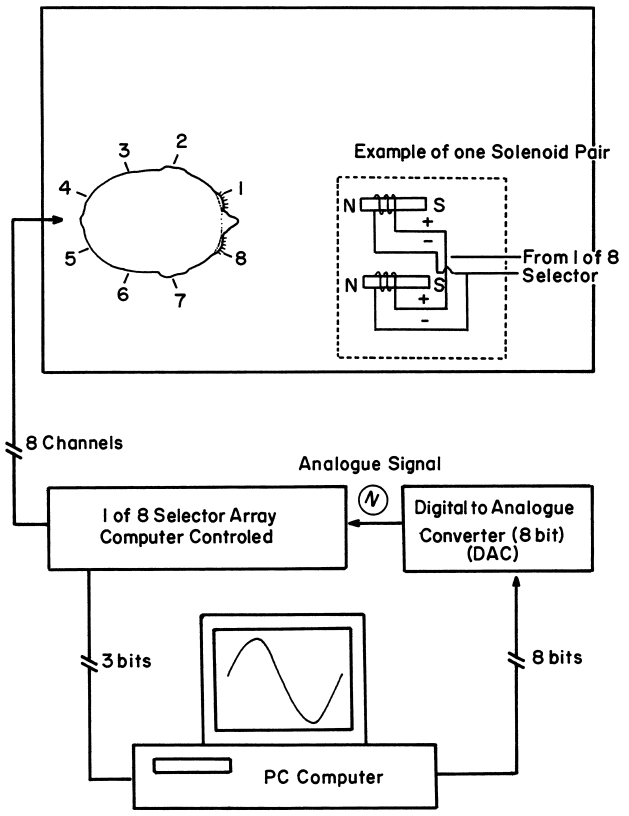

Fig. 1. Diagram of the device designed to produce rotational, circumcerebral transient magnetic fields. Numbers 1–8 in the upper panel refer to the positions of the eight solenoid pairs from a dorsal view of a subject's head.

whereby the subject is aware that temporal judgments will be required. With this method attention of the subject is directed in real time to information that is related to the passage of time [19]. We predicted temporal distortions in estimations by counterclockwise but not clockwise circumcerebral stimulation by pulsed magnetic fields because they would interfere (move in the opposite direction) with the coherent, rostrocaudal waves moving through the right hemisphere.

Fourteen young (20–26 years old), right-handed men and women volunteered (2% bonus marks in first year course) for the experiment. They were told the experiment was concerned with relaxation to minimize expectancy effects. After fixing a set of opaque swimming goggles over the subject's eyes and placing cotton in the ears, eight solenoids were attached equidistantly to a velcro strip that was placed around the circumference of the subject's head (Fig. 1). When activated, the strength of the field adjacent to the scalp was between 50 and 100 mG (5 and 10 μT).

The subject was instructed that midway through a 5 min pattern, the experimenter would place a stop watch in the left hand of the subject. Upon instruction the subject was to start the stop watch and then stop it when 10 s had elapsed. To discern the individual differences in subjective time estimation each subject was asked to estimate 10 s in two successive trials each separated by about 30 s. The second trial was employed as the baseline value. Each subject was exposed to six sequential configurations each of which was 5 min in duration. An estimation (which required about 30 s) of the time interval was then completed after a 2.5 min exposure to each of the six configurations. When the estimate was completed, the stop watch was removed. There was no statistically significant difference between the two groups for their baseline estimates of 10 s ($F(1, 13) = 1.71$, $P > 0.05$).

Each subject had also been assigned sequentially to one of two conditions (three men, four women per condition): clockwise or counterclockwise arrangement of the eight solenoids. For the clockwise condition, solenoid 1 was placed over the right prefrontal region such that solenoids 1–4 were equally spaced (45 deg) over the right hemisphere and solenoids 5–8 were equally spaced over the left hemisphere along the orbitotemporal plane. For the counterclockwise position, solenoid 1 was placed over the left prefrontal region such that solenoids 1–4 were placed over the left hemisphere and solenoids 5–8 were placed over the right hemisphere. Consequently, the counterclockwise arrangement generated a field sequence that moved in a rostral to caudal direction along the left hemisphere but in a caudal to rostral direction along the right hemisphere. The reverse motion occurred for the clockwise montage.

The shapes and frequency characteristics of the two patterns employed in the present study, burst-firing and frequency modulated ('Thomas pattern'), have been published elsewhere [15,17]. The two patterns were generated by software processed by an XT (Zenith Z148) computer that delivered the information within the files to each of the solenoids in the same sequential order (solenoid 1–8). Each signature or pattern was generated by converting a

Table 1
Parameters for each of the six configurations presented to subjects in either a clockwise or counterclockwise circumcerebral rotation

Configuration	1	2	3	4	5	6
Signature	Burst-firing			Frequency modulated		
Temporal pattern	1	2	3	1	2	3
Pixel durations (ms)	1	1	3	1	1	3
Interstimulus (ms)	1	1	3000	1	1	3000
Commutator rate (ms)	20	100	200	20	100	200
Change in rate (ms)	+2	+20	−2	+2	+20	−2

Table 2
Means and standard deviations for the differences (in seconds) between subjective estimates of 10-s intervals after the field presentations compared with baseline values for the groups who received the configurations in either a clockwise or counterclockwise rotation

	Clockwise		Counterclockwise		Effect size (%)
Configuration	M	SD	M	SD	(Eta-squared)
1	1.0	1.0	2.5	2.1	14
2	0.6	1.1	3.5	1.9	47
3	1.0	0.9	3.9	2.5	42
4	1.1	1.3	4.4	2.1	51
5	1.5	1.8	6.1	3.9	40
6	1.1	1.2	5.1	3.5	40

series of numbers between 0 and 255 to the equivalent voltage which ranged from −5 to +5 V. The computer-to-port latency was about 50 μs.

The manipulable parameters for this system were the pixel duration or the time in milliseconds for each point of each value between 0 and 255 that comprised a pattern (between 300 and 10,000 points), the time between signatures (or interstimulus interval), and the duration of the total package. We selected interstimulus times of 1 and 3000 ms because of their success in previous studies [3,4,15]. By employing a batch file, a third level of temporal organization, package duration, was also created. From empirical criteria, the duration of each file (pattern and interstimulus interval) was 5 min and the time between batches was 2 min such that a total of 40 min was required to execute the experiment.

The eight solenoids were activated singularly in a linearly repeating order (1, 2, … 8, 1, 2, … 8, etc.) in accordance with these two additional variables: duration of the presentation of the fields at each solenoid and the change in the rate of presentation of the field at each solenoid. These values are also presented in Table 1. For example configurations 2 and 5 had durations of 100 ms at each solenoid and a change in rate of presentation of 20 ms. Consequently the field presentation was 100 ms at the first solenoid, 120 ms at the second solenoid, 140 ms at the third solenoid and 340 ms at the eighth solenoid. The only difference between configuration 2 and 5 was the shape of the pattern. The pulse pattern that was 200 ms in duration with a rate of change of −2 ms (sequence 3) was accelerated with the activation of each solenoid such that the duration of the field at each pair of solenoids changed successively from 200 to 186 ms.

The means and standard deviations for the net differences (in seconds) between the estimated 10-s interval subtracted from the baseline estimate for each sequence are shown in Table 2 for the groups that received the clockwise and counterclockwise rotations. Except for the first sequence, the group exposed to the counterclockwise rotation displayed significantly (all F-values (1,13) between 7.90 and 13.01, $P < 0.01$) longer subjective durations. The mean and standard deviation for the average (all six configurations) overestimation of the 10-s interval was 4.1 ± 2.2 s for the group who received the counterclockwise presentations compared to the overestimation of 1.0 ± 0.9 s for the group who received the clockwise presentations ($F(1, 12) = 10.64$, $P < 0.01$; eta-squared = 47%.

Two-way analysis of variance with one level repeated (configuration) demonstrated a strong, statistically significant difference between the subjective estimates of time for the subjects exposed to the counterclockwise relative to the clockwise presentation of the rotating cerebral fields. In addition to the expected effect over time of the presentation of the configurations ($F(5, 60) = 4.87$, $P < 0.001$), there was a statistically significant interaction ($F(5, 60) = 2.57$, $P < 0.05$; partial eta-squared = 18%) between the direction of the rotation of the circumcerebral fields and configuration. Symmetrical post-hoc analyses employing (Scheffe's $P < 0.05$) and paired t-tests (for each treatment separately) indicated that the primary sources of this interactions were the greater subjective temporal dilations during configurations (2 and 5) that involved successive accelerations of 20 ms for the group that received the counterclockwise presentation. These differences were not displayed by the group who received the same sequences but in a clockwise direction.

When the drift in subjective estimates over the six presentations was accommodated by covariance, the most significant dilation in subjective time was displayed during the counterclockwise rotation when the configuration (#5) containing the frequency modulated ('Thomas') pattern was presented for 100 ms and the rate of change was 20 ms at each solenoid. After this exposure the time estimation (M, SD) was 12.2 ± 1.8 s compared with 9.1 ± 2.1 s for the group who received the clockwise rotation ($F(1, 12) = 8.74$, $P = 0.01$). As the numbers of rotations during 2.5 min for configuration 5 would be 1103, the extension of subjective time by 2.6 s would be equivalent to a disruption of about 23 ms per rotation. The distortion of subjective time was not as large when the burst-firing pattern, which would have generated fewer pulses within the 20 ms rate of change, was applied. The adjusted (for drift) means and standard deviations for the subjective time estimations for the group that received the counterclockwise and clockwise directions for this pattern was 9.6 ± 3.4 and 8.3 ± 2.8 s, respectively ($F(1, 12) < 1.00$; $P > 0.05$).

The results are consistent with the research of Llinas and Ribary [10] who have been isolating the temporal and spatial characteristics of the electromagnetic correlate of the neural coherence [16] that subserves cognition and with the literature concerning the neural correlates of time perception [7,11,14]. Conscious awareness, as inferred by perception of time intervals, involves a process that may be recreated approximately every 20–25 ms and may be affected by right hemispheric activity. Interference with this process by pulsed magnetic fields of approximately 10 μT intensity moving spatially against the rostrocaudal phase shifting waves would have occurred within the right hemisphere only during the counterclockwise rotations.

Most pharmacological treatments that distend subjective estimates of time display mild opiate characteristics [6,12,13]. The burst-firing and particularly the frequency modulated patterns employed in this study have evoked elevated nociceptive thresholds [3,17] or have encouraged subjective experiences consistent with hedonia [4]. Although we cannot exclude the possibility that exposure for 2.5 min to the circumcerebral fields may have released intrinsic opiate compounds, if this alternative etiology produced the temporal dilatation than it must have been responsive specifically to counterclockwise rotation.

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